



Information Series 91

International System (SI) of Units in Hydrogeology

W. Ceroici

Alberta
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Groundwater Division

Alberta Research Council
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INTERNATIONAL SYSTEM (SI) OF UNITS IN HYDROGEOLOGY

W. Ceroici

INTRODUCTION

In 1970 the White Paper on Metric Conversion proposed that Canada adopt the International System of Units (SI). The proposal was accepted and the Metric Commission was established in 1971 to implement the conversion to SI.

The switch to SI means a complete revision of units used in hydrogeology. This report aims to familiarize Canadian hydrogeologists with SI units and to encourage standard use of units early in the changeover.

ACKNOWLEDGMENTS

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STRUCTURE OF THE INTERNATIONAL SYSTEM OF UNITS

The metric system known as the *Système International d'Unités* (SI) is based on seven base units and two supplementary units which are purely geometrical and will not be discussed here (Table 1). The Canada Standards Association (1973) defines the base units as:

length

The metre is the length equal to 1 650 763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels $2p_{10}$ and $5d_5$ of the krypton -86 atom.

mass

The kilogram is a unit of mass equal to the mass of the international prototype of the kilogram.

time

The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium -133 atom.

electric current

The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of

negligible circular cross-section, and placed 1 metre apart in a vacuum, would produce between these conductors a force equal to 2×10^{-7} newtons per metre of length.

thermodynamic temperature

The kelvin is the fraction $1/273.16$ of the thermodynamic temperature of the triple point of water. In everyday situations temperature is expressed in degrees Celsius ($^{\circ}\text{C}$).

amount of substance

The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 of a kilogram of C^{12} .

luminous intensity

The candela is the luminous intensity, in the perpendicular direction, of a surface of $1/600\,000$ square metres of a black body at the temperature of freezing platinum under a pressure of 101 325 newtons per square metre.

The base units are convenient and acceptable units from which derived units are formed. Derived units are base units expressed algebraically using symbols for multiplication and division.

SI has two major advantages over the traditional imperial system.

- (1) Each physical quantity has only one unit and the product or quotient of any two SI units yields the unit of the resulting quantity.
- (2) All multiples and submultiples of a quantity are related by a factor of ten (i.e., 10^n or 10^{-n}). Greek and Latin prefixes indicate denary steps (Table 2).

RULES OF STYLE

SI is an unambiguous system governed by strict rules of style, some of which are mentioned below. Detailed information about the system may be found in the references on page 4.

THE DECIMAL

In Canada the decimal marker is represented by a point on a line (e.g., 20.5).

The decimal is always preceded by a zero in numbers less than one.

The use of the comma to separate groups of digits should be avoided, since in some countries the comma is used as a decimal point.

Numbers should be written and listed in groups of three with each group separated by a space (the use of a half-space is not incorrect and is useful for listing numbers) (e.g., 5 000 000 and 0.050 345).

A solitary four digit number in text does not require a space.

TABLE 1
SI Base and Supplementary Units

Quantity	Unit	Symbol
Base Units		
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampère	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd
Supplementary Units		
plane angle	radian	rad
solid angle	steradian	sr

SYMBOLS

Symbols are not followed by a period.

Exponents are used for units which are squared or cubed.

Symbols should not be pluralized.

Compound symbols formed by dividing units contain a virgule or solidus (/) to indicate division and compound units formed by multiplying units contain a dot (·) to indicate multiplication.

When a quantity is expressed, a prefix should be chosen so that the numerical value lies between 0.1 and 1000 (e.g., 0.0001 m is better expressed as 1 mm).

Spelling out unit names should be avoided. In the conversion tables (Appendix B), unit names are spelled out for clarification since they are mixed with other units.

TABLE 2
Denary Steps of SI

Prefix	Symbol	Factor By Which Unit is Multiplied
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^9
mega	M	10^6
kilo	k	10^3
hecto	h	10^2
deca	da	10^1
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}

HYDROGEOLOGICAL SI UNITS

After looking at the proposals of the USA Federal Metric Panel for Hydrogeology and after corresponding with the Hydrology Division of Fisheries and Environment Canada, a proposed SI list was circulated among the staff of the Groundwater Division of the Alberta Research Council. Appendix A contains the list of suggested SI units to be used in hydrogeology.

Appendix B contains tables for converting SI units to other systems of measurement. When converting measurements, approximate values should be converted to approximate not to exact values; if the average hydraulic conductivity of an aquifer is 500 igpd/ft², the correct conversion to SI would be 0.03 cm/s rather than 0.0283 cm/s. Conversion should also be made to coherent units, that is, those units derived by multiplying or dividing the base units (Martinek, 1977).

PUMP TEST FORMULAS

Pump testing formulas, listed below, are also modified to make them compatible with SI units. For additional information about these formulas or other methods of pump test analysis, refer to Kruseman and De Ridder (1970).

FORMULAS

Steady state flow in semi-confined aquifers

Hantush-Jacob Method

$$T = \frac{2.3Q}{2\pi\Delta s_T}$$

$$C = \frac{(r_o/1.12)^2}{T}$$

Unsteady state flow in semi-confined aquifers

Walton's Method

$$T = \frac{Q}{4\pi s} W(u, r/L)$$

$$S = \frac{4Tt}{r^2} u$$

Steady state flow in confined aquifers

Thiem's Method

drawdown vs time plot

$$T = \frac{Q}{2\pi (s_1 - s_2)} \ln \frac{r_2}{r_1}$$

1 and 2 refer to observation wells

drawdown vs distance plot

$$T = \frac{2.3Q}{2\pi \Delta s_T}$$

Unsteady state in confined aquifers

Theis's Method

$$T = \frac{Q}{4\pi s} W(u)$$

$$S = \frac{4Ttu}{r^2}$$

Theis's Recovery Method

$$T = \frac{2.3Q}{4\pi \Delta s'}$$

Jacob's Method

drawdown vs time plot

$$T = \frac{2.3Q}{4\pi \Delta s}$$

$$S = \frac{2.25Tt_o}{r^2}$$

Aquifers pumped by a large diameter well

Papadopoulos-Cooper's Method

$$T = \frac{Q}{4\pi s} F(u_w, B)$$

$$S = \frac{4Ttu_w}{r_w^2}$$

Calculation of twenty-year safe yield (Q_{20})

$$Q_{20} = \frac{TH}{127}$$

Symbol definitions and units

Symbol		Unit
Q	discharge rate	m ³ /d
T	transmissivity	m ² /d
S	storage coefficient	dimensionless
t	time	day
t ₀	time at 0 drawdown	day
s	drawdown	m
s'	residual drawdown	m
s _T	steady state drawdown	m
r	distance of observation well from pumping well	m
r ₀	radius at 0 drawdown	m
r _w	radius of pumping well	m
c	hydraulic resistance of semi-pervious layer	day
L	leakage factor	m
W(u)		
W(u,r/L)	well functions	
	(from tables)	
F(u _w ,B)		
u	$\frac{r^2 S}{4Tt}$	
u _w	$\frac{r_w^2 S}{4Tt}$	
Q ₂₀	twenty-year safe yield	L/s
H	total available drawdown	m

REFERENCES

- Canada Standards Association (1973): The International System of Units (SI); Rexdale, Ontario. 29 p.
- Council of Ministers of Education, Canada (1976): The Metric Guide; Ontario Institute for Studies in Education for the Council of Ministers of Education, Canada, Toronto, Ontario, 104 p.
- Kruseman, G.P. and N.A. De Ridder (1970): Analysis and Evaluation of Pumping Test Data; International Institute for Land Reclamation and Improvement, Bulletin 11, 200 p.
- Martinek, A. (1977): Metric System (SI) in Engineering Technology; Waterloo, Ontario, 194 p.
- Metric Commission Canada (1978): How to Write SI; Metric Commission Canada, Ottawa, Ontario, 8 p.
- Smith, C.F. (1975): The Metric Manual; Coles Publishing Company Ltd., Toronto, Ontario, 69 p.

APPENDIX A. LIST OF RECOMMENDED HYDROGEOLOGICAL SI UNITS

<u>Quantity</u>	<u>Symbol</u>	<u>Unit</u>
Length		
precipitation	mm	millimetre
evaporation	mm	millimetre
transpiration	mm	millimetre
elevation	m	metre
pipe size	mm	millimetre
geography:		
inches	mm	millimetre
feet	m	metre
miles	km	kilometre
drawdown, well depth, depth in well, etc.	m	metre
aquifer thickness	m	metre
aquifer width, length	km	(if less than 1 km use m)
Area		
stream cross-section	m ²	metre ²
land area (small)	m ²	metre ²
land area (large)		
mile ²	km ²	kilometre ²
acre	ha	hectare
pipes, conduits	m ² , mm ²	metre ² , millimetre ²
water area	km ² , m ²	kilometre ² , metre ²
Volume		
water storage (small)	L	litre
water storage (large)	km ³ , m ³	kilometre ³ , metre ³
Rate of Discharge		
if rate less than 1000 L/s	L/s	litre/second
if rate greater than 1000 L/s	m ³ /s	metre ³ /second
Miscellaneous		
hydraulic conductivity	cm/s	centimetre/second
permeability (intrinsic)	mm ²	millimetre ²
transmissivity	m ² /d	metre ² /day
diffusivity	m ² /s	metre ² /second
velocity	cm/s	centimetre/second
electrical conductivity	mS/m	microsiemens/metre
temperature	°C	degree Celsius
pressure (head)	m	metre
pressure (barometric)	kPa	kilopascal
viscosity (dynamic)	Pa·s	pascal second
viscosity (kinematic)	m ² /s	metre ² /second
specific capacity	m ² /s	metre ² /second
density	g/cm ³	gram/centimetre ³
solution concentration	mol/L	mole/litre

APPENDIX B. CONVERSION TABLES

Most conversion factors in the tables are from various technical papers. Calculations corroborated values extracted from publications, and previously unpublished factors were derived.

B 1. LENGTH

	kilometres	metres	centimetres	miles	yards	feet	inches
1 kilometre =	1	1×10^3	1×10^5	0.6214	1.0936×10^3	3.2808×10^3	3.9370×10^4
1 metre =	1×10^{-3}	1	1×10^{-2}	6.2137×10^{-4}	1.0936	3.2808	39.3701
1 centimetre =	1×10^{-5}	1×10^{-2}	1	6.2137×10^{-6}	1.0936×10^{-2}	3.2808×10^{-2}	0.3937
1 mile =	1.6093	1.6093×10^3	1.6093×10^5	1	1.760×10^3	5.280×10^3	6.336×10^4
1 yard =	9.1440×10^{-4}	0.9140	91.440	5.6818×10^{-4}	1	3	36
1 foot =	3.0480×10^{-4}	0.3048	30.480	1.8939×10^{-4}	0.3333	1	12
1 inch =	2.540×10^{-5}	2.540×10^{-2}	2.540	1.5783×10^{-5}	2.7778×10^{-2}	8.3333×10^{-2}	1

B 2. AREA

	kilometres ²	metres ²	centimetres ²	miles ²	feet ²	inches ²	hectares	acres
1 kilometre ² =	1	1×10^6	1×10^{10}	0.3861	1.0764×10^7	1.550×10^9	1×10^2	2.4711×10^2
1 metre ² =	1×10^{-6}	1	1×10^4	3.8610×10^{-7}	10.7637	1.550×10^3	1×10^{-4}	2.4711×10^{-4}
1 centimetre ² =	1×10^{-10}	1×10^{-4}	1	3.8610×10^{-11}	1.0764×10^{-3}	0.1550	1×10^{-8}	2.471×10^{-8}
1 mile ² =	2.590	2.590×10^6	2.590×10^{10}	1	2.7878×10^7	4.0145×10^9	2.590×10^2	6.40×10^2
1 foot ² =	9.2903×10^{-8}	9.2903×10^{-2}	9.2903×10^2	3.5870×10^{-8}	1	144	9.2903×10^{-6}	2.2957×10^{-5}
1 inch ² =	6.4516×10^{-10}	6.4516×10^{-4}	6.4516	2.4910×10^{-10}	6.9444×10^{-3}	1	6.4516×10^{-8}	1.5942×10^{-7}
1 hectare =	1×10^{-2}	1×10^4	1×10^8	3.8610×10^{-3}	1.0764×10^5	1.550×10^7	1	2.4711
1 acre =	4.0468×10^{-3}	4.0468×10^3	4.0468×10^7	1.5625×10^{-3}	4.3560×10^4	6.2727×10^6	0.4047	1

B 3. VOLUME

	kilometres ³	metres ³	centimetres ³	yards ³	feet ³	inches ³	litres	Imperial gallons	U.S. gallons	acre-feet
1 kilometre ³ =	1	1 x 10 ⁹	1 x 10 ¹⁵	1.3079 x 10 ⁹	3.5314 x 10 ¹⁰	6.1023 x 10 ¹³	1 x 10 ¹²	2.2008 x 10 ¹¹	2.6417 x 10 ¹¹	8.1071 x 10 ⁵
1 metre ³ =	1 x 10 ⁻⁹	1	1 x 10 ⁶	1.3079	35.3137	6.1023 x 10 ⁴	1 x 10 ³	2.2008 x 10 ²	2.6417 x 10 ²	8.1071 x 10 ⁻⁴
1 centimetre ³ =	1 x 10 ⁻¹⁵	1 x 10 ⁻⁶	1	1.3079 x 10 ⁻⁶	3.5314 x 10 ⁻⁵	6.1023 x 10 ⁻²	1 x 10 ⁻³	2.2008 x 10 ⁻⁴	2.6417 x 10 ⁻⁴	8.1071 x 10 ⁻¹⁰
1 yard ³ =	7.6456 x 10 ⁻¹⁰	0.7646	7.6456 x 10 ⁵	1	27	4.6656 x 10 ⁴	7.6456 x 10 ²	1.6827 x 10 ²	2.0197 x 10 ²	6.1984 x 10 ⁻⁴
1 foot ³ =	2.8317 x 10 ⁻¹¹	2.8317 x 10 ⁻²	2.8317 x 10 ⁴	3.7037 x 10 ⁻²	1	1.7780 x 10 ³	28.317	6.2321	7.4805	2.2957 x 10 ⁻⁵
1 inch ³ =	1.6387 x 10 ⁻¹⁴	1.6387 x 10 ⁻⁵	1.6387 x 10 ⁷	2.1433 x 10 ⁻⁵	5.7870 x 10 ⁻⁴	1	1.6387 x 10 ⁻²	3.6065 x 10 ⁻³	4.329 x 10 ⁻³	1.3285 x 10 ⁻⁸
1 litre =	1 x 10 ⁻¹²	1 x 10 ⁻³	1 x 10 ³	1.3079 x 10 ⁻³	3.5314 x 10 ⁻²	61.024	1	0.2201	0.2642	8.1071 x 10 ⁻⁷
1 Imperial gallon =	4.5437 x 10 ⁻¹²	4.5437 x 10 ⁻³	4.5437 x 10 ³	5.943 x 10 ⁻³	0.1606	2.7727 x 10 ²	4.5437	1	1.2003	3.6846 x 10 ⁻⁶
1 U.S. gallon =	3.7854 x 10 ⁻¹²	3.7854 x 10 ⁻³	3.7854 x 10 ³	4.9512 x 10 ⁻³	0.1337	2.310 x 10 ²	3.7854	0.8331	1	3.0697 x 10 ⁻⁶
1 acre-foot =	1.2335 x 10 ⁻⁶	1.2335 x 10 ³	1.2335 x 10 ⁹	1.6133 x 10 ³	4.3560 x 10 ⁴	7.5272 x 10 ⁷	1.2335 x 10 ⁶	2.7140 x 10 ⁵	3.2576 x 10 ⁵	1

B 4. DISCHARGE RATE

	litres/second	metres ³ /second	metres ³ /day	imperial gallons/minute	U.S. gallons/minute	feet ³ /second	acre-feet/day
1 litre/second =	1	1 x 10 ⁻³	86.40	13.201	15.852	3.531 x 10 ⁻²	7.005 x 10 ⁻²
1 metre ³ /second =	1 x 10 ³	1	8.640 x 10 ⁴	1.320 x 10 ⁴	1.585 x 10 ⁴	35.313	70.045
1 metre ³ /day =	1.157 x 10 ⁻²	1.157 x 10 ⁻⁵	1	0.153	0.184	4.088 x 10 ⁻⁴	8.107 x 10 ⁻⁴
1 imperial gallon/minute =	7.575 x 10 ⁻²	7.576 x 10 ⁻⁵	6.546	1	1.201	2.675 x 10 ⁻³	5.307 x 10 ⁻³
1 U.S. gallon/minute =	6.308 x 10 ⁻²	6.308 x 10 ⁻⁵	5.450	0.833	1	2.228 x 10 ⁻³	4.421 x 10 ⁻³
1 foot ³ /second =	28.321	2.832 x 10 ⁻²	2.446 x 10 ³	3.738 x 10 ²	4.488 x 10 ²	1	1.984
1 acre-foot/day =	14.276	1.428 x 10 ⁻²	1.234 x 10 ³	1.884 x 10 ²	2.262 x 10 ²	0.504	1

B 5. HYDRAULIC CONDUCTIVITY

	centimetres/second	metres/day	imperial gallons/ day/foot ²	U.S. gallons/ day/foot ²
1 centimetre/second =	1	864	1.766×10^4	2.121×10^4
1 metre/day =	1.157×10^{-3}	1	20.44	24.54
1 imperial gallon/ day/foot ² =	5.663×10^{-5}	4.893×10^{-2}	1	1.201
1 U.S. gallon/ day/foot ² =	4.716×10^{-5}	4.075×10^{-2}	0.8327	1

B 6. PERMEABILITY

$$1 \text{ metre}^2 = 1.013 \times 10^{12} \text{ darcy}$$

$$1 \text{ darcy} = 0.831 \text{ metres/day (at } 20^\circ \text{C)}$$

B 7. TRANSMISSIVITY

	metres ² /day	imperial gallons/ day/foot	U.S. gallons/ day/foot
1 metre ² /day =	1	67.05	80.52
1 imperial gallon/ day/foot =	1.491×10^{-2}	1	1.201
1 U.S. gallon/ day/foot =	1.242×10^{-2}	0.8326	1

B 8. PRESSURE

	pounds/inch ²	feet of water	millimetres of mercury	inches of mercury	kilopascal	kilogram-force/metre ²	kilogram-force/centimetre ²
1 pound/inch ² =	1	2.31	51.711	2.036	6.895	7.027×10^{-6}	7.027×10^{-2}
1 foot of water =	0.433	1	22.40	0.883	2.986	3.046×10^{-6}	3.046×10^{-2}
1 millimetre of mercury =	1.934×10^{-2}	4.46×10^{-2}	1	3.937×10^{-2}	0.133	1.359×10^{-7}	1.359×10^{-3}
1 inch of mercury =	0.491	1.133	25.40	1	3.385	3.452×10^{-6}	3.452×10^{-2}
1 kilopascal =	0.145	0.335	7.499	0.295	1	1.020×10^{-6}	1.020×10^{-2}
1 kilogram-force/metre ² =	1.423×10^{-5}	3.284×10^{-5}	7.356×10^{-6}	2.896×10^{-5}	9.807×10^{-5}	1	1×10^{-4}
1 kilogram-force/centimetre ² =	14.23	32.84	7.356×10^2	28.96	98.067	1×10^{-4}	1

B 9. DENSITY

	grams/centimetre ³	pounds/inch ³	pounds/foot ³	pounds/U.S. gallon	pounds/imperial gallon	kilograms/metre ³	kilograms/litre
1 gram/centimetre ³ =	1	3.613×10^{-2}	62.429	8.345	10.017	1×10^3	1
1 pound/inch ³ =	27.680	1	1.728×10^3	2.310×10^{-2}	2.773×10^2	2.768×10^4	27.680
1 pound/foot ³ =	1.602×10^{-2}	5.787×10^{-4}	1	0.134	0.160	16.018	1.602×10^{-2}
1 pound/U.S. gallon =	0.120	4.329×10^{-3}	7.463	1	1.201	1.198×10^2	0.120
1 pound/imperial gallon =	9.983×10^{-2}	3.606×10^{-3}	6.250	0.833	1	99.827	9.983×10^{-2}
1 kilogram/metre ³ =	1×10^{-3}	3.613×10^{-5}	6.243×10^{-2}	8.345×10^{-3}	1.002×10^{-2}	1	1×10^{-3}
1 kilogram/litre =	1	3.613×10^{-2}	62.429	8.345	10.017	1×10^3	1

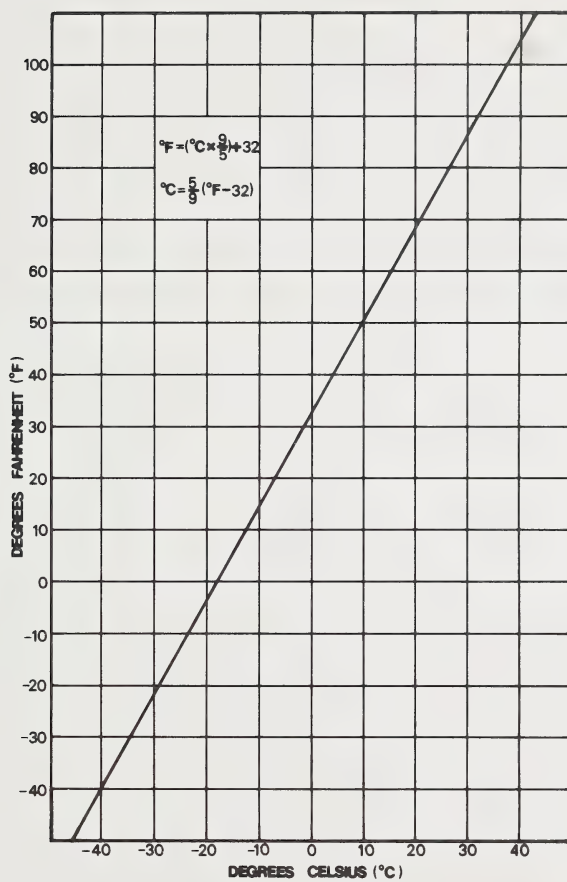
B10. DYNAMIC VISCOSITY

	pascal·seconds	poise	poundal second/ foot ²	pound-force second/foot ²
1 pascal·second =	1	10.0	0.672	0.021
1 poise =	0.10	1	6.72×10^{-2}	2.1×10^{-3}
1 poundal second/foot ² =	1.488	14.88	1	3.125×10^{-2}
1 pound-force second/ foot ² =	47.619	4.762×10^2	32.002	1

B11. KINEMATIC VISCOSITY

	metres ² /second	millimetres ² /second	feet ² /second	inches ² /second	stokes
1 metre ² /second =	1	1×10^6	10.764	1.55×10^3	1×10^4
1 millimetre ² /second =	1×10^{-6}	1	1.076×10^{-5}	1.55×10^{-3}	1×10^{-2}
1 foot ² /second =	9.290×10^{-2}	9.29×10^4	1	1.44×10^2	9.29×10^2
1 inch ² /second =	6.452×10^{-4}	6.452×10^2	6.944×10^{-3}	1	6.452
1 stoke =	1×10^{-4}	1×10^2	1.076×10^3	0.155	1

B12. TEMPERATURE





N.L.C. - B.N.C.



3 3286 04981790 7